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Total Ozone Mapping Spectrometer measurements of aerosol absorption from space: Comparison to SAFARI 2000 ground-based observations

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[1] The capability to detect the presence of absorbing aerosols in the atmosphere using space-based near-UV observations has been demonstrated in the last few years, as indicated by the widespread use by the atmospheric sciences community of the Total Ozone Mapping Spectrometer (TOMS) aerosol index as a qualitative representation of aerosol absorption. An inversion procedure has been developed to convert the unique spectral signature generated by the interaction of molecular scattering and particle absorption into a quantitative measure of aerosol absorption. In this work we evaluate the accuracy of the near-UV method of aerosol absorption sensing by means of a comparison of TOMS retrieved aerosol single scattering albedo and extinction optical depth to ground-based measurements of the same parameters by the Aerosol Robotic Network (AERONET) for a 2-month period during the SAFARI 2000 campaign. The availability of collocated AERONET observations of aerosol properties, as well as Micropulse Lidar Network measurements of the aerosol vertical distribution, offered a rare opportunity for the evaluation of the uncertainty associated with the height of the absorbing aerosol layer in the TOMS aerosol retrieval algorithm. Results of the comparative analysis indicate that in the absence of explicit information on the vertical distribution of the aerosols, the standard TOMS algorithm assumption yields, in most cases, reasonable agreement of aerosol optical depth (±30%) and single scattering albedo (±0.03) with the AERONET observations. When information on the aerosol vertical distribution is available, the accuracy of the retrieved parameters improves significantly in those cases when the actual aerosol profile is markedly different from the idealized algorithmic assumption.

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1. Introduction

[2] The role of atmospheric aerosols in the global climate is one of the largest remaining sources of uncertainty in the assessment of global climate change. Aerosols directly affect the energy balance of the Earth-atmosphere system, through the processes of scattering of solar radiation, which redistributes the incoming solar energy in the atmosphere, and absorption (of both solar and infrared radiation), which transforms radiative energy into internal energy of the absorbing particles and heats up the atmosphere. In addition, aerosols, through their role as cloud condensation nuclei, have an indirect effect on climate by affecting the albedo and lifetime of clouds [*Haywood and Boucher*, 2000].

[3] The cooling effect of aerosols, associated with the backscattering to space of a fraction of the incoming solar energy, is considered to be a very important counteracting factor of the well known warming effect of the greenhouse gases. The absorption by aerosol particles of a fraction of the incident sunlight and, for certain aerosol types, infrared radiation, results in a heating of the atmosphere. Thus aerosol absorption reduces the cooling effect commonly associated with aerosol particles. Although, the impact of aerosol absorption on climate is still a subject of considerable debate [*Penner et al.*, 2003], recently published theoretical analysis suggest that black carbon may be the second most important global warming substance (in terms of its direct radiative forcing effect) after carbon dioxide, and larger than methane [*Jacobson*, 2002]. The role of aerosol absorption effects on climate is, therefore, an issue that needs to be better understood in order to reduce the currently large uncertainties of its climatic effect.

[4] In this paper, we present and discuss the results of the application of the near-UV method to observations by the Total Ozone Mapping Spectrometer (TOMS), on board the Earth Probe (EP) satellite (also known as EP-TOMS), to retrieve aerosol single scattering albedo during the Southern African Regional Science Initiative (SAFARI 2000) campaign [*Swap et al.*, 2002]. A brief discussion of some theoretical aspects associated with the quantification of aerosol absorption is carried out in section 2,

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followed by a short review of commonly used remote sensing approaches to measure aerosol absorption in section 3. In section 4, the physical basis of the near-UV approach is given, and a brief description of the TOMS aerosol algorithm is presented. In section 5, the TOMS retrieved single scattering albedo and optical depth are compared to collocated retrievals of the same parameters from observations by the Aerosol Robotic Network (AERONET). The last section includes additional discussion, a summary of results and conclusions of the analysis.

6. Summary and Conclusions

[39] The performance of the near-UV approach of measuring aerosol absorption from space has been evaluated making use of AERONET ground-based observations of optical depth and single scattering albedo during SAFARI 2000. The availability of lidar profiles during the campaign allowed a detailed analysis of the sensitivity of the retrieval technique to the aerosol vertical distribution.

[40] The optical depth validation indicates that the TOMS retrieval result is within 30% of the Sun photometer measurements for 82% of the 127 comparison cases, when the aerosol profile is represented as a single layer at 3 km above the ground. This conclusion is consistent with previous algorithm performance assessments [*Torres et al.*, 2002a, 2002b]. Sources of uncertainty are the aerosol vertical distribution, subpixel cloud contamination effects, and, to a lesser extent, the surface reflectivity.

[41] A total of 120 TOMS-AERONET coincidences at 8 sites were used to evaluate the accuracy of the TOMS derived single scattering albedo. The evaluation of the single scattering albedo retrieval with reference to the AERONET results, shows than in 63% of the cases the satellite retrieval agrees within 0.03 with the AERONET results, whereas the agreement is within 0.05 in 87% of the coincidences used in the analysis. This results indicate that the near-UV measurements can be used to measure the aerosol single scattering albedo from space with an accuracy equivalent to the one reported by the AERONET project of ±0.03 [*Dubovik et al.*, 2002] for aerosol optical depth values of about 0.4. It should be said that the accuracy of the AERONET single scattering albedo product improves as the aerosol layer becomes optically thicker. Thus, at the large optical depth values (0.6 and higher) encountered during SAFARI 2000, the accuracy of the AERONET absorption measurements should be better than 0.03. However, no estimates of the AERONET accuracy for large aerosol loads are available in the literature.

[42] On four days during the campaign, MPLNET measurements of the aerosol vertical distribution were available within 30 min of the satellite overpass. The lidar profiles were used as input to generate look up tables for the retrieval in lieu of the standard vertical distribution assumption. When using the actual aerosol profiles the accuracy of the retrieved aerosol optical depth improved significantly in the cases when the measured and assumed profiles were very different. As it would be expected, no significant effect was observed when the assumed profile resembled the measured one. The evaluation of the accuracy of the single scattering albedo showed that even in the one case that the measured vertical distribution deviated significantly from the simple one-layer assumption the retrieved ssa using the standard 3 km profile was still very close (within 0.01) to the ground-based measurement. The use of the actual profiles resulted in an additional improvement of the accuracy of the space-based measurements.

[43] The reported results support the use of the 3 km aerosol layer height for the retrieval of smoke properties in the absence of accurate vertical distribution information over the continental areas. As shown by *Anderson et al.* [1996], using lidar measurements during TRACE-A, the aerosol vertical distributions over Africa and South America are not too different. Elevated aerosol layers, however, may result downwind of the source areas. As shown in this work, the use of actual vertical profile information enhances the accuracy of the near-UV method.

[44] To date the near-UV technique is the only tested and validated method of measuring aerosol absorption from space. The multidecade long TOMS record has been used to produce the only available satellite global data set on aerosol absorption, from 1979 to present. The Ozone Monitoring Instrument (OMI) on the EOS-Aura satellite, launched in July 2004, will continue the record of aerosol absorption into the future. The Aura mission is one of several satellites flying in formation in the so-called A-train, that includes the AQUA and Cloud Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) platforms. The OMI aerosol algorithm [*Torres et al.*, 2003] takes advantage of the OMI extended spectral coverage (270 to 500 nm), the smaller-than-TOMS footprint (3×13 km for aerosol retrieval), and the simultaneous availability of aerosol related information from other A-train sensors, to enhance the science value of the aerosol information. For instance, the nadir aerosol vertical distribution measured by CALIPSO will undoubtedly benefit the quality of the OMI aerosol products.

[45] In order to reduce the uncertainty associated with the absorption effects of aerosols in both climate and air quality applications, it is necessary to continue and improve current aerosol absorption sensing capabilities. Because of the weak wavelength dependence of the imaginary refractive index of soot (the aerosol component responsible for most of the absorption effect of anthropogenic aerosols), near-UV absorption retrievals of the imaginary refractive index can be extrapolated to the visible and near-IR.

[46] The TOMS measurements have played a fundamental role in the development and testing of the near-UV method, and OMI is certainly an improvement over TOMS capabilities. The Advanced Earth Orbiting Satellite II (ADEOS II) Global Imager (GLI) sensor [*Nakajima et al.*, 1998] was the first satellite instrument to combine near-UV, visible and near-IR channels at a spatial resolution suitable for accurate aerosol retrieval. Unfortunately, the satellite failed just a few months after launch. To take full advantage of the potential of the near-UV method, future satellite sensing missions should include measurements in the near-UV to derive aerosol absorption information, that combined with measurements in the visible and near-infrared will significantly contribute to improve the understanding of the radiative transfer effect of aerosols on the Earth-atmosphere system.